Opportunistic Power Control for Wireless Ad hoc Networks

Abdorasoul Ghasemi, Karim Faez
Department of Electrical Engineering
AmirKabir University of Technology, Hafez Avenue, Tehran, Iran, 15914
{arghasemi, kfaez}@aut.ac.ir

Abstract: *Opportunistic power control can be used as a generalized framework for distributed power control in wireless networks. In this paper, we investigate this scheme for wireless ad hoc networks where channel state changes due to the mobility of nodes. Using opportunistic power control, a node increases its power in good and decreases it in bad channel condition. Considering some real restrictions on nodes mobility and maximum allowable transmission power in each time slot, we use opportunistic power control to determine the power of mobile nodes in each time slot in a time-division multiple access (TDMA) wireless ad hoc network. We compare the network throughput and power consumption of this scheme with the target tracking approach that aim at hitting a Signal to Interference plus Noise Ratio (SINR) target in all time slots. Simulation results show that opportunistic algorithm inherently has a scheduling property that results into a significant improvement in throughput and power consumption of the network and makes it more appropriate for distributed power control in wireless Ad hoc networks.*

Keywords: Ad Hoc Networks, power control, distributed Algorithm

1 Introduction

Ad hoc wireless networks are exposed to time varying channel due to effects such as multipath fading, shadowing, and path losses. A general strategy to combat these effects is through the dynamic allocation of resources based on the states of the user channel [2]. Transmitter power is one of these resources that need to assign dynamically.

Transmission power control (TPC) for wireless ad hoc networks, is the procedure of determining the power level for each packet (time slot) and in each node that should be done in a distributed fashion [3]. The importance of this problem has twofold: reducing power consumption in nodes and increasing the network capacity by limiting the mutual interference between nodes. The former addresses the limited battery life of mobile nodes where all nodes are mobile terminals with small size and weight. The later addresses the spatial reuse of resources in the network by limiting the multi-user interference [4]. TPC problem is usually studied in conjunction with scheduling problem. The purpose of scheduling is to schedule nonconflicting transmissions in order to achieve efficient spatial reuse.

TPC can affect all layers of the protocol stack in wireless ad hoc networks and it is well known that TPC is a cross layer problem i.e. it should be done in different time scales and considering the all layers of protocol stack simultaneously. Many researches indicate that a good TPC in one or more layers of the protocol stack can significantly improve the network performance [3].

A main category of power control algorithms in MAC layer is those that try to reserve the minimum floor that is required by the source and destination to communicate reliably. To this end, these algorithms use control signals like request to send (RTS) and clear to send (CTS) to reserve the required floor and adapting the power level based on the estimation of channel state between the transmitter and receiver. Reserving the floor is necessary to limit the interference of the neighboring transmitters. Control signals can be used to keep silence or to bind the transmission power of the potential interfering terminals [5]. The main problem of these algorithms is related to interleaving and using control signals between data signals.

Another approach that is borrowed from the cellular networks is iterative power control algorithms that are done locally in the mobile nodes. The aim of power control in cellular network is to assign each user a transmitter power level that ensures an acceptable connection for it [6]. In these algorithms, mobile users adapt to a time varying radio channel by regulating their transmitter powers. The main advantage of this scheme is that it can be implemented totally asynchronously which is appropriate for the uplink power control in cellular and wireless ad hoc networks. The focus of this paper is on iterative power control for wireless ad hoc networks.

The common properties of these iterative algorithms to ensure convergence to the fixed point, if any exists, were unified in the Yates' framework [7]. One of the algorithms that belong to this frame work is the Foschini-Miljanic algorithm that works as a target tracking power control algorithm to ensure a specified Signal to Interference plus Noise Ratio (SINR) for each user in different channel state.

This algorithm is used in [4] for joint scheduling and power control for multiple access problem in contention-based wireless ad hoc networks. The objective was on next neighbor transmission where nodes are to send packets to their respective receivers while, at the same time, satisfy a set of SINR constraints. It was shown that distributed power control that was originally developed for cellular networks are directly applicable to emerging wireless ad hoc networks.

Recently a new framework was introduced by Sung for distributed power control in wireless networks named as opportunistic power control [1]. This framework is applicable to systems supporting opportunistic communications and heterogeneous service requirements. The idea behind this new algorithm is that for data services it is no longer needed to maintain a certain SINR in all time slots and it is possible to schedule the transmission of different users according to their channel quality in an opportunistic way. The common properties of an iterative function to be opportunistic and convergence of the algorithm were studied in [1]. Simulation results of this algorithm show a significant improvement of network throughput and power consumption compared to Foschini-Miljanic algorithm for cellular networks.

In this paper, we use opportunistic power control for ad hoc wireless network and compare the results of this algorithm with Foschini-Miljanic algorithm. Simulation results for different scenarios show that opportunistic power control can also be used for ad hoc wireless networks and improves the power consumption and capacity of the network.

The rest of the paper is organized as follow. In section 2, we describe the system model and problem statement. In sections, 3 and 4 two algorithms for power control are described. In section 5, the simulation results and discussion on them are presented.

2 System Model and Problem Statement

A wireless ad hoc network is modeled with 2N mobile users that make N pairs of transmitters and receivers (TR pairs). The transmitter nodes distributed randomly and uniformly in a square shape area of size L×L. The corresponding receiver of each transmitter is located randomly in a circle around it of radius R. In simulations, R is changing as a varying percentage of size L. In this paper, we want to consider the power control and its effect on mutual interference at the MAC layer, since we assume the single hop transmissions only. Parameter R can be interpreted as the performance of the routing algorithm to specify the next hop for transmission and isolated the interference caused by good routing algorithm, small R, and poor routing algorithm, large R. It is completely possible for a receiver to be in the range of other transmitters, rather than its corresponding transmitter, which is, depends on parameter R.

To model the mobility, positions of TR pairs are changed randomly at the beginning of each time slot with probability p and with probability 1-p they keep their positions in the previous time slot. The probability p is used to control the speed of link changes that must be slow enough for distributed power control algorithms to work. Fig. 1 shows an instance of a network in a time slot where N=10, L=10, R=0.2. The same number indicates a TR pair. Note that it is possible for a TR pair to be close and free of others interference like TR pair number 10 or be far and in the interference range of others like TR pairs 5, 7.

At the beginning of each time slot, each transmitter must decide on the level of its power. Let $\mathbf{p} = (p_1, p_2, ..., p_N)$ denote the power vector of the network nodes in each time slot, where p_i is the transmit power of user i. Equation (1) gives the SINR at the receiver of mobile node i.

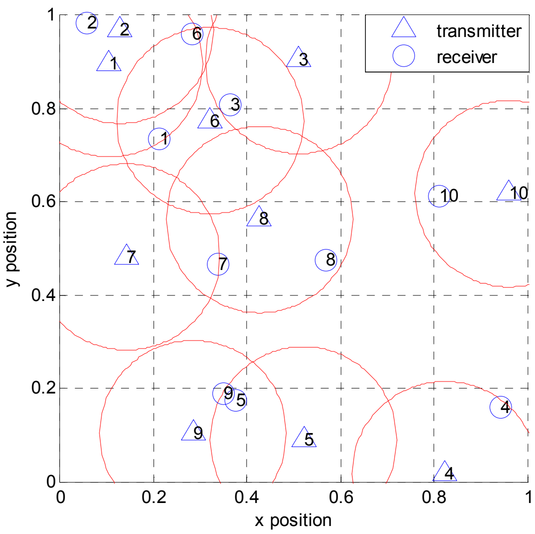


Figure 1. An instance of the network

$$\Gamma_i(p) = \frac{p_i}{R_i(\mathbf{p})} \tag{1}$$

Where

$$R_i(\mathbf{p}) = \frac{1}{G_{ii}}(\eta_i + \sum_{j \neq i} G_{ij} p_j) \tag{2}$$

In these equations G_{ij} denotes the link gain between the transmitter of mobile node j and receiver of mobile node i and η_i is the noise power at the receiver of mobile node i. $R_i(\mathbf{p})$ is the *effective interference* of mobile node i. In our model of wireless ad hoc network, the link gain between a transmitter t and receiver r is determined by:

$$G_{ij} = \frac{1}{1 + [(x_r - x_t)^2 + (y_r - y_t)^2]^{\alpha/2}} \tag{3}$$

Where (x_r, y_r) and (x_t, y_t) present transmitter and receiver locations within the network and α is the path loss exponent of the signal. The extra"+1 " term in the denominator is inserted to model the fact that the links gain are kept below 1 and the signal power at the receiver is never more than the corresponding power used at the transmitter. It is assumed that each transmitter can estimate the level of noise power and the interference that is encountered in the previous slot.

The objective of the iterative power control algorithm is to determine the power level of each node at the beginning of each time slot using an iterative form function as in (4).

$$\mathbf{p}^{(n+1)} = \boldsymbol{I}(\mathbf{p}^{(n+1)}) \tag{4}$$

Where

$$\boldsymbol{I}(\mathbf{p}) = (I_1(\mathbf{p}), I_2(\mathbf{p}), \ldots, I_n(\mathbf{p})) \tag{5}$$

$\mathbf{p}^{(n)}$ is the power vector of the network at time slot n and $\mathbf{p}^{(n+1)}$ denotes the power vector at time slot $n+1$.

For evaluation of the power control algorithm, throughput and power consumption are computed. We use the Shannon capacity formula to measure the network throughput.

$$C_T = W \sum_i \log_2(1 + \Gamma_i(\mathbf{p})) \tag{6}$$

To obtain the average performance, we averaged C_T and the consumed power over a long period. Another criterion for the performance evaluation is the percentage of time slots that users have a SINR above some threshold β that is considered in simulations.

3 Fochini-Miljanic TPC Algorithm

The Foschini-Miljanic algorithm aims at finding a suitable power vector so that the SINR requirement of all users can be met. If γ_i denotes the target SINR of user i, the set of iterative equations (7) is used to adjust the power of each mobile node.

$$p_i^{(n+1)} = \frac{\gamma_i}{\Gamma_i(\mathbf{p}^{(n)})} p_i^{(n)}, \qquad for\ i = 1,2,....,N \tag{7}$$

This iterative function is standard i.e. it has the monotonicity and scalability conditions of the Yates' framework; hence, the power vector converges to the fixed point, if any exits, given any initial power vector.

The maximum power level that a node can use for transmission is limited which is denoted by p_{max}. Therefore, the iterative functions of (7), change as in (8.

$$p_i^{(n+1)} = \min(p_{\max}, \frac{\gamma_i}{\Gamma_i(\mathbf{p}^{(n)})} p_i^{(n)}),\ for\ i = 1,\ldots,N \tag{8}$$

Since the constant function is standard and the minimum of the two standard functions is a standard one, this iterative function is also converging to the fixed point. However, the existence of the fixed point is not guaranteed and strongly depends on the value of target SINR. In [4] to resolve this problem a centralized scheduling phase is used to limit the amount of the interference. In the other words, this scheduling phase is responsible for coordinating independent users' transmissions to eliminate strong level of interference inherent to the network. This drawback of the Foschini-Miljanic algorithm restricts its application in ad hoc wireless network where there is not any central coordinator. The target SINR to ensure the convergence is dependent on the number of users, the maximum allowable transmitted power and the channel gain matrix. In our simulation, we choose target SINR low enough to ensure the convergence of the algorithm in almost all cases.

3 Opportunistic TPC Algorithm

Opportunistic power control aims at determining the power level at each time slot based on the channel condition. Despite the Foschini-Miljanic algorithm that increases the power level in bad channel condition to ensure the required SINR, in opportunistic scheme the user increases his power in good channel condition and decreases it in bad channel condition. For an iterative function to be opportunistic, it must be type-II standard that is defined in [1]. It is shown that the set of functions (9) is opportunistic iterative functions.

$$p_i^{(n+1)} = \frac{\xi_i}{R_i(\mathbf{p}^{(n)})}, \qquad for\ i = 1,2,....,N \tag{9}$$

That is keeping the product of the signal power and the effective interference to a constant ξ_i. Note that this function is decreasing with respect to the effective interference in spite of the Foschini-Miljanic algorithm.

In our simulations, we use the bounded power vector of (10), which is a type-II standard function.

$$p_i^{(n+1)} = \min(p_{\max}, \frac{\xi_i}{R_i(\mathbf{p}^{(n)})}), for\ i = 1,...,N \tag{10}$$

As we will seen by simulation, this iterative function includes some form of scheduling internally and can be used fully distributed in wireless ad hoc networks.

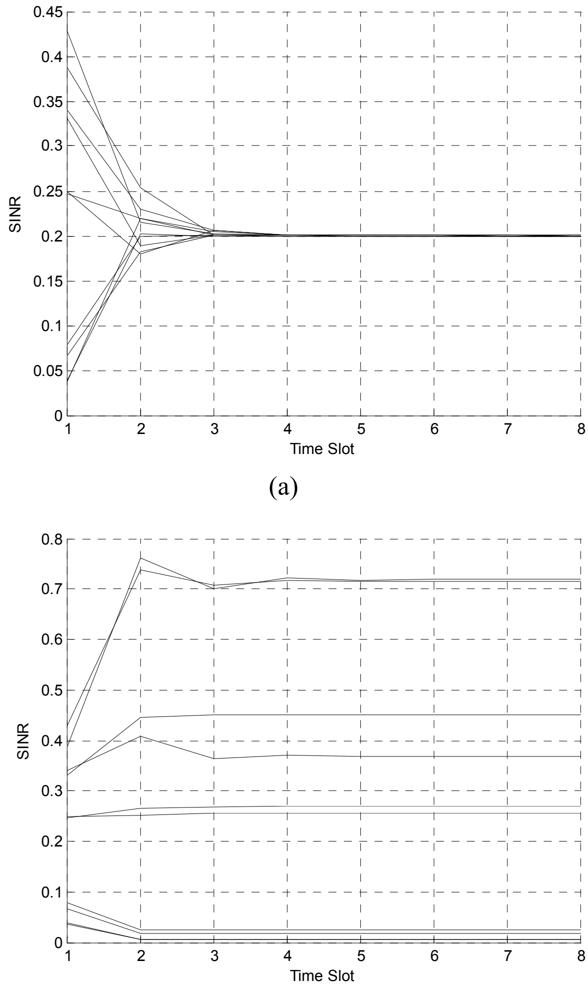
4 Numerical Results

To simulate the operation and performance of the two algorithms, we use the system model described in section two. The simulation parameters are summarized in table 1.

Fig. 2, Shows the evolution and convergence of the SINR for the two algorithms with parameters $\gamma_i = 0.2$, $\zeta_i = 1.0$. In this case, the Foschini-Miljanic algorithm converges to the target SINR for all 10 users. For the opportunistic algorithm, as can be seen from the figure, only six of 10 users reach SINR above the threshold SINR, which must be around the γ_i. In the other words, the four users that have bad channel conditions deferring to increase their power that results into better SINR for other users. This property of the opportunistic algorithm acts as a distributed scheduling algorithm and as we will see next, this results in to increasing the network throughput and decreasing the power consumption.

Table 1: Simulation Parameters

Path loss exponent (α)	4
Number of users (N)	10
L	10
Destination Range(R)	2
Noise power (η)	1
Mobility factor (p)	0.2
Maximum power ($p_{\max}$)	5



(a)

(b)

Figure 2: Convergence of power levels for 10 users, (a) Foschini-Miljanic algorithm, (b) Opportunistic algorithm

In the second simulation, we verify the operation of the two algorithms by depicting the power changes with respect to channel variations. With the parameters mentioned in table 1, the range of channel gain is about $(0.05,1)$. We use $\gamma_i = 0.2$ and $\zeta_i = 3.0$ in this simulation. Fig. 3, Shows the variation of power and channel gain for TR pair number one. It can be seen from Fig. 3, that in Foschini-Miljanic algorithm the power increases as the channel gain decreases and in the opportunistic algorithm, the power increases as the channel gain increases.

To compare the power consumption and capacity of the two algorithms we should normalize the achievable throughput and the consumed power in some way. One way is to adjust the algorithm parameters, γ_i in Foschini-Miljanic and ξ_i in opportunistic algorithm, such that the two algorithms consumed the same power and then compare their throughput. We use the average throughput of each slot normalized by the average consumed power to compare algorithms. We call this parameter TNP. The throughput is computed using (6).

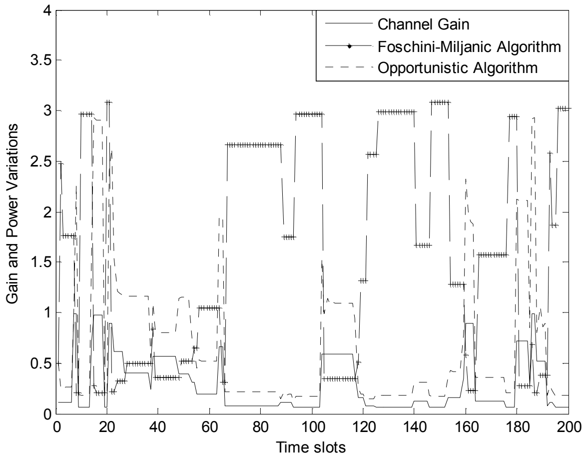


Figure 3: Comparison of power variation with channel gain in two algorithms for user number one

Fig. 4, shows this parameter for 1000 simulation time slots. The parameters of this simulation are $\gamma_i = 0.2$ and $\zeta_i = 3.0$. As the figure shows, the opportunistic algorithm has better performance. If we average the TNP values in 1000 time slots, the opportunistic algorithm shows better performance of about 2.4 times compared to Foshini-Miljanic Algorithm.

The average SINR for the first 200 time slots is shown in Fig. 5. It is clear that the opportunistic algorithm does not guarantee any specific SINR in all time slots. This is a drawback of this algorithm. The percentage of times that the average SINR falls below the SINR threshold is about 10%. The SINR threshold is selected slightly below the target SINR in Foschini-Miljanic Algorithm. We use $\beta = 0.18$.

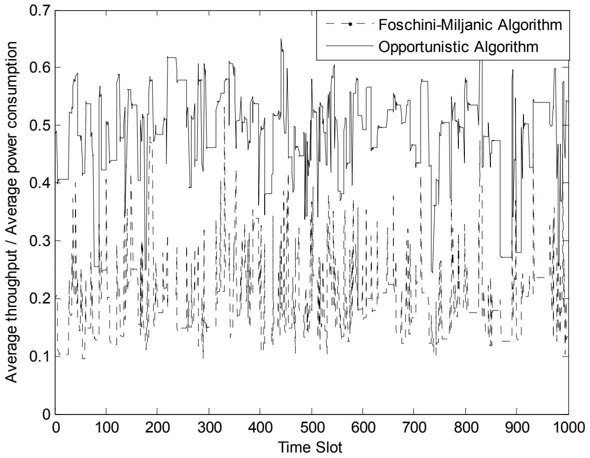


Figure 4: Average throughput normalized by the average consumed power in 1000 consecutive time slots

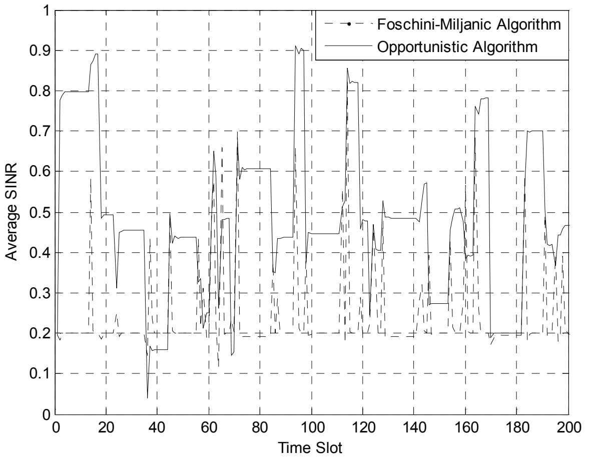


Figure 5: Average SINR in the first 200 time slots

Table 2: Average Performance of the Opportunistic Algorithm

R	$\frac{Avg.\, TNP\ of\ opportunistic\ Alg.}{Avg.\, TNP\ of\ Foschini-Miljanic\ Alg}$	$Avg.\, SINR < \beta$ (% of time slots)
0.2	2.4	10.22
0.5	3.7	17.5
0.9	3.75	32.2

Another important parameter in the evaluation of the opportunistic algorithm is the sensitivity of the algorithm to the level of the interference in the network. We compute the above parameters for different values of R, the range in which the corresponding receiver of each transmitter is located, in 10000 time slots. The results are summarized in table 2. It is inferred form this table that the advantages of the opportunistic algorithm compared to Foschini-Miljanic algorithm is more highlighted in high interference network situation. However, the percentage of times that SINR falls below the threshold SINR is increased.

Briefly, we could say that the opportunistic algorithm has better performance in network throughput and power consumption than the Foschini-Miljanic but cannot guarantee a specified SINR for users.

5 Conclusion

It this paper we investigate the opportunistic power control algorithm for TDMA wireless ad hoc networks. We use opportunistic power control to combat the channel variations, which are resulted from the node mobility. We compare the results of this algorithm with Foschini-Miljanic algorithm, which tries to hit a target SINR in all channel conditions. Network throughput, power consumption and a required minimum SINR are the criteria that are investigated in comparing two algorithms. Simulation results show that the performance of the opportunistic algorithm is better than the target tracking method and depends on the level of interference in the network. In addition, it is inferred that opportunistic algorithm has a scheduling algorithm inherently, which makes it a good option for fully distributed power control in wireless ad hoc networks.

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